DRAFT
MISSION DEFINITION AND REQUIREMENTS DOCUMENT

for the

Supernova / Acceleration Probe (SNAP)

University of California, Berkeley
Lawrence Berkeley National Laboratory

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Draft 1.0d

1. Science Objectives

1.1 Overview

Recent measurements carried out by the Supernova Cosmology Project (SCP) have made the startling discovery that the expansion of the universe is accelerating. This result is based on the Hubble diagram for Type Ia supernovae, and has been corroborated by results from several experiments, both similar and complementary. Einstein's General Theory of Relativity requires that some mechanism must drive this expansion rate either through a new form of energy, such as a new vacuum energy density (cosmological constant), or a yet unknown kind of particle or field fundamental to the creation and formation of the universe. The source of this acceleration is more powerful than the gravity from all seen and unseen forms of matter and known energy. Theorists are unable to explain the observed effect and so follow-up measurements would have a tremendous impact on the field of fundamental physics. The Supernova / Acceleration Probe (SNAP) Mission is expected to provide a understanding of the mechanism driving the acceleration of the universe. Over the mission lifetime, the satellite observatory is capable of measuring at least 2,000 distant Type Ia supernovae. These measurements will map out in detail the expansion rate of the universe at epochs varying from the present to 10 billion years in the past. SNAP will measure the key cosmological parameters Ω_m and Ω_Λ as well as determine the spatial curvature of the universe and thus provide a fundamental test of the theory of inflation – the theoretical mechanism that drove the initial formation of the universe. This sensitive experiment uses Type Ia supernovae as an astronomical standard candle to provide a distance scale, which, combined with the redshift obtained from the spectral lines from the supernova and its host galaxy, determine the cosmological parameters and ultimately the nature of the "missing energy" in the universe.

1.2 Summary Description of the Science Instruments

The SNAP observatory will have an approximately 2 meter diameter rigid lightweight primary mirror with a focal plane covering one degree. The camera will have approximately one-half billion pixels, representing the largest imager ever fabricated. In order to facilitate thermal management of the observatory and instruments, and reduce light emissions from the earth's limb, the spacecraft is placed in high earth elliptical orbit spending majority of the time above the radiation belts. SNAP would be launched from a Delta IV-M or equivalent rocket. Our baseline science mission plan calls for continuous operation of SNAP for four years. This provides time to classify and accurately measure 2,000 distant Type Ia supernova, obtain final reference images and spectra, while interleaved with wide-field weak lensing surveys.

2. Reference Mission

2.1 Baseline Science Mission

The SNAP reference science mission assumes a 2.0 meter primary mirror with low obscuration and a large 1° field-of-view with diffraction-limited images (in I-band). The mission repeatedly samples approximately 22 fixed fields near the north or south ecliptic poles every four days searching for new supernova explosions. The discovered supernovae are then measured by photometry for the next four to eight months while the luminosity waxes and wanes. The selected observing fields minimize zodiacal light background and obscuration due to dust in our Galaxy. A low-resolution spectrum is taken of each supernova at peak brightness. The satellite is expected to be able to analyze up to 2,000 supernovae with redshifts ranging from 0.3 to 1.7.

The optics design for the SNAP satellite is expected to be a variant of a three-mirror telescope explored by M. Paul (M.Paul, Rev.Optics 14 p.169 1935; P.Robb Appl.Opt.17 p.2677 1978). The chief idea is to combine a concave primary paraboloid and a convex secondary paraboloid to approximate an afocal reducer, followed by a highly concave spherical tertiary. The secondary, located at the center of curvature of the tertiary, is then modified to eliminate the spherical aberation of the tertiary. A 1.8 meter telescope of this type with a 1° field-of-view and a worst case 0.1 arcsec rms radius image was described in 1982 (R. Angel, Woolf & H. Epps, SPIE 332, p.134 1982; also J. McGraw, et al SPIE 331 p.137, 1982). In this design, the short focus of the tertiary places the detector buried deep within the secondary-tertiary space, making the detector inaccessible and blocking its own light and also needs a fairly large secondary 40% of primary size. Placing the tertiary significantly behind the primary was shown by Willstrop in 1984 to have significant advantages for wide-field imaging (Willstrop, R.V., MNRAS 210, 597-609, 1984). Finally, with the increased space between tertiary and primary a 45° optical flat can be inserted to fold the optical paths. A key to the success of the design is the feedback of a pointing error signal from the focal plane to the attitude control of a high stability spacecraft.

The size of the SNAP primary mirror has a dramatic effect on the science capabilities of the mission. The combination of the light gathering power of the mirror and the diffraction limit imposed by the aperture determine the number of supernovae that can be studied in a fixed interval, and varies as the *fourth power* of the aperture diameter. The requirement of diffraction limited optics at I-band has been selected to make best use of the capabilities of the photometric instruments and minimize exposure times. The wide-field optical photometry will also perform with the highest accuracy if the star images are properly sampled. A plate-scale of approximately 10 arcsec/mm has been selected as a best compromise between a wide field of view and achieving the best photometric accuracy. The mission is restricted to the minimum fairing dimensions of the Atlas III, Delta III, and the Delta IV-M composite fairing. Given the space required for spacecraft bus and telescope tube the aperture is not fixed by fairing diameter, rather by total length. Without deployed components, the largest aperture that is likely to fit is 2.2 meter, at this size the mission would also become mass restricted. For apertures below 2.0m, detector performance characteristics become critical. From simulation, it has been found that the observational redshift limit, z_{max}, for well-measured supernovae drops linearly with the diameter. So that reducing the mirror diameter from 2.0m to 1.8m reduces the pratical z_{max} from 1.7 to 1.5. The reference science mission for the observatory is summarized in Table 1.

Table 1. SNAP Reference Mission

Aperture	2.0 meter
Field-of-view	0.7 square degrees
Optical resolution	diffraction-limited at I-band
Wavelength coverage	350nm - 1700nm
Solar avoidance	70°
Temperature	Telescope 270 - 290 K (below thermal background)
Fields of study	North and South Ecliptic Caps
Pointing	Active Image Feedback
Plate Scale	10.5 arcsec/mm

2.2 Photometry of Supernovae

The primary measurement of the mission is to obtain the peak brightness vs. redshift relationship of Type Ia supernovae out to a redshift of 1.7. These data will require taking accurate photometric observations of the supernova over the light-curve. An example of the restframe B-band light-curve is shown in Figure 1. It has been found experimentally that the supernova peak brightness can be standardized when viewed through a B-band filter where the B-band is defined in the *restframe* of the supernova (defined at rest with respect to the supernova). Therefore the photometry must seek to define an appropriate bandpass depending on the redshift of the supernova. The importance of this bandpass selection can be seen in Figure 2, where the B-band is superimposed over an example Type Ia supernova spectrum. The bandpasses are defined by having an extensive set of "redshifted B-band" filters, one for each small range of redshift. With the large field-of-view of the imager, it is possible to "batch process" large numbers of supernovae in a given observation so that the objectives can be met with a large number of filters. The filter set shown below in table 2 are Johnson B-band filters with central wavelength of $\lambda = 0.44 \times 1.15^{n-1}$, where n= 1,..,9.

Table 2. Redshifted B-band filters

Filter Number	*Effective redshift*	*B-band Center λ (μm)*	*B-band Bandpass $\delta\lambda$ (μm)*
1	0.00	0.44	0.11
2	0.15	0.51	0.13
3	0.32	0.58	0.15
4	0.52	0.67	0.17
5	0.75	0.77	0.19
6	1.01	0.88	0.22
7	1.31	1.02	0.25
8	1.66	1.17	0.29
9	2.06	1.35	0.34

Figure 1. B-band Light-curve for Type Ia Supernovae corrected for redshift and lightcurve timescale.

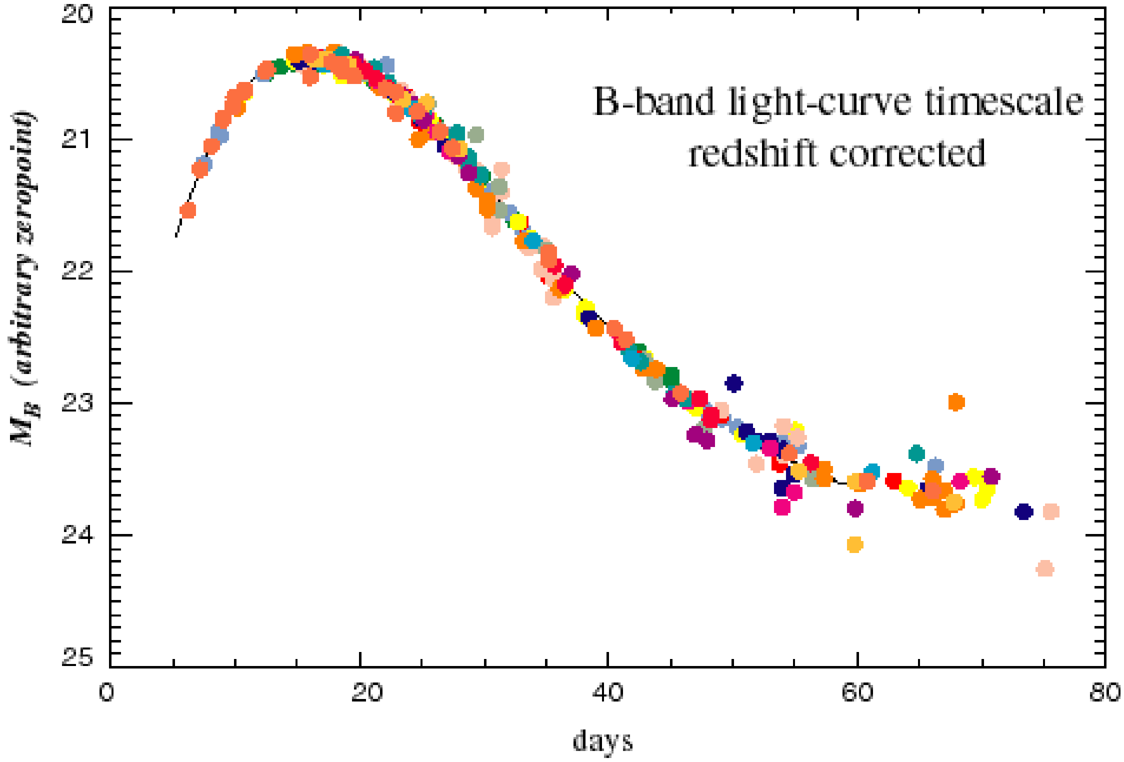
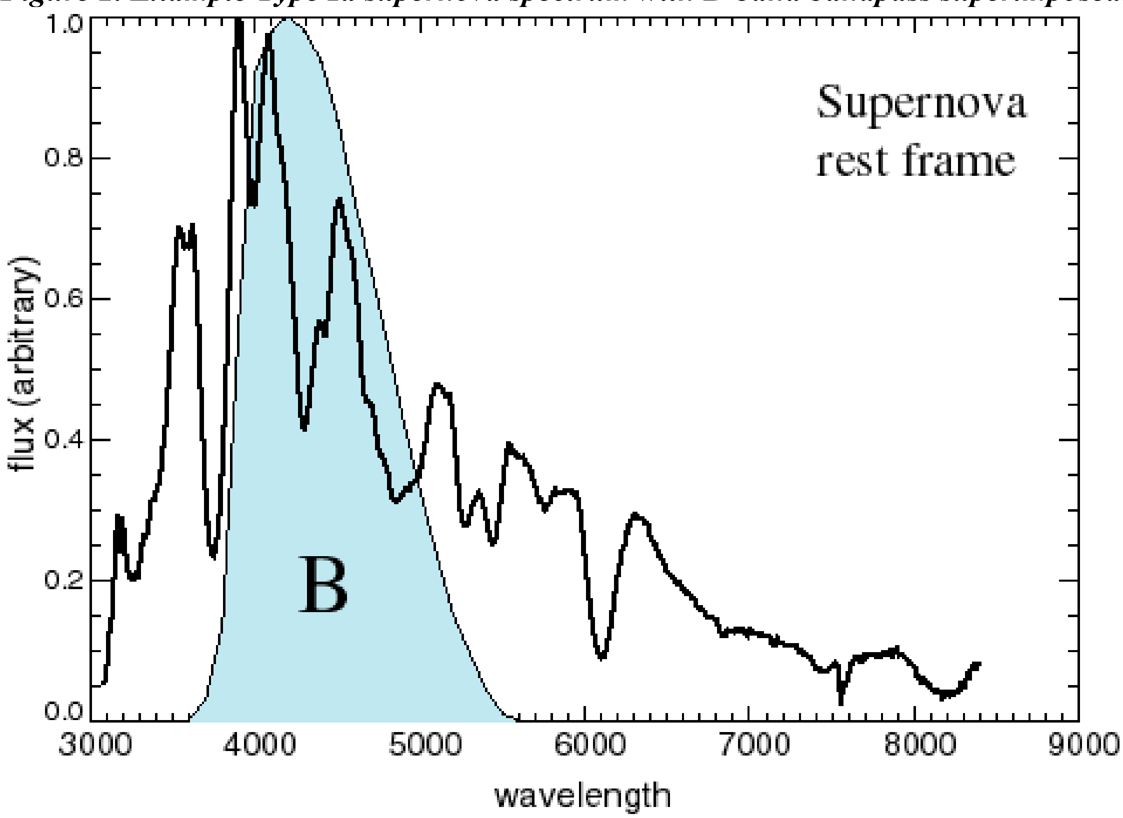


Figure 2. Example Type Ia supernova spectrum with B-band bandpass superimposed.



3. Science Requirements

3.1 Level 1 & Level 2 Science Requirements

The purpose of this section is to define the objectives of the investigation and the baseline measurements to be accomplished. The SNAP baseline science objective is to obtain a high statistics calibrated dataset of Type Ia supernovae to redshifts of 1.7 with excellent control over systematic errors. To achieve this, SNAP must perform the following:

1. Perform Wide Field Imaging of the celestial poles from 0.35 to 1.7 microns with I-band diffraction-limited optics.
2. Perform multiple-filter Wide Band Imaging photometry in multiple filter bands to determine supernovae color.
3. Detect supernovae at redshifts in the range of $0.3 < z < 1.7$.
4. Derive supernova peak luminosity to 2% (statistical) or better through multiple measurements over the supernovae light-curve.
5. Obtain supernova spectrographic observations near peak intensity with a resolution of 100 ($\lambda/\delta\lambda$) over 0.35 to 1.7 microns.
6. Measure supernovae host galaxy redshifts.
7. Identify and analyze over 2000 Type 1a supernovae.

The statistical sample is to be 2 orders of magnitude greater than the current published set of ~42 supernovae, and is to extend much farther in distance and time. From this dataset we expect to obtain a 2% measurement of the mass density of the universe, a 5% measurement of the vacuum energy density, a 5% measurement of the curvature, and a 5% measurement of the equation of state of the "dark energy" driving the acceleration of the universe. Systematic studies will include a measurement of the "reddening" of spectra from "ordinary dust" in the hosts galaxies of supernovae up to redshifts of 1.7, and detection of potential "grey dust" sources. Using Type Ia supernovae as standard candles will require measurement of the key luminosity indicators: the lightcurve peak and width. The redshift of the host galaxy of the supernova needs to be measured, supernova type identified, and spectral features studied. Effects correlated with host galaxy morphology and the position of the supernova in the host galaxy can also be studies due to the excellent resolution possible from space. These properties may indicate differences in stellar population from which the supernova came and therefore can be used to test whether the intrinsic brightness of the supernova changes systematically with redshift.

These objectives are achieved through the definition of the SNAP Level 1 and Level 2 science requirements. The key Level 1 requirements meet the objectives of supernovae quantity, quality, spectroscopy, and survey size:

Table 3. Draft Level 1 Science Requirements

1.1	Obtain over 2000 classified Type Ia supernovae for analysis in the redshift range 0.3 < z < 1.7
1.2	Derive supernova color and relative peak luminosity on average to 2% (statistical)
1.3	Obtain supernova spectrographic observations near peak intensity with a resolution R~100 over 0.35 to 1.7 microns wavelength.
1.4	Perform deep multi-color photometric surveys with field sizes of approximately 15 and 300 square degrees

From simulation studies the Level 2 requirements are derived. Many of these requirements assume an optimization of both the science objectives of measuring the properties of the dark energy along with resulting trade-studies that have evaluated analysis objectives.

Table 4. Draft Level 2 Science Requirements

1.1	**Obtain over 2000 classified Type Ia supernovae for analysis in the redshift range 0.3 < z < 1.7**
1.1.1	Observatory to be a 2 meter diameter telescope with I-band diffraction limited optics sensitive from 0.35 to 1.7 microns.
1.1.2	Instrumented field of view of telescope to be approximately one degree (~0.7 square degrees)
1.1.3	Perform wide field imaging of regions of low dust extinction near the ecliptic poles with a solar avoidance angle of 70 degrees.
1.1.4	Photometric observations are to be zodiacal light limited.
1.2	**Derive supernova color and relative peak luminosity on average to 2% (statistical)**
1.2.1	Obtain photometric measurements in redshifted B-band broadband filters.
1.2.2	Obtain peak and off-peak (plus and minus 4 days rest-frame) multi-band photometric measurements of SNe with S/N=30
1.2.3	Measure risetime with detection at average 2 days after explosion at 3.8 magnitudes below peak with S/N>3, and peak-to-tail ratio of SNe.
1.2.4	Obtain peak and off-peak multi-band photometric measurements with at least 10 points on the SNe lightcurve
1.2.5	Measure SNe color and extinction with up to six visible light and three infra-red broadband filters from 0.35 to 1.7 microns
1.3	**Obtain supernova spectrographic observations near peak intensity with a resolution R~100 over 0.35 to 1.7 microns wavelength.**
1.3.1	Measure supernova peak spectrum to identify and classify SNe
1.3.2	Measure supernova spectra vs. epoch for subset of SNe with z<0.7
1.3.3	Measure the broad (200A) Silicon (6150A rest-frame) and Sulfur (5350A rest-frame) features
1.3.4	Obtain spectroscopic measurement of calibration standards
1.4	**Capable of performing deep multi-color photometric surveys with field sizes of approximately 15 and 300 square degrees.**
1.4.1	Mission operations and avoidance angles to permit wide field surveys up to 300 square degrees
1.4.2	Minimum four visible broadband filters for photo-z measurements to facilitate weak-lensing surveys.

3.2 Instrumentation Requirements

The satellite is expected to carry two key instruments, a 1° FOV wide field imager sensitive to wavelengths from 350 nm – 1700 nm, and a low resolution 350 nm – 1700nm spectrograph. The capabilities of these instruments must be a good match to the science requirements for the satellite. In particular, the instrumentation must provide all the elements of the supernova studies, namely: 1) early detection of supernovae, 2) U,B,V,R & I-band restframe photometry (up to λ=1.7 μm) to follow the photometric lightcurve of the supernova as it waxes and wanes and measure the supernova color, 3) spectra at peak brightness to classify the supernova and provide spectral diagnostics, and 4) photometric redshifts of the host galaxies in advance of supernova follow-up. Each of these elements can be expressed as a set of explicit requirements for the data products:

Detection. Early detection of Type Ia supernovae with S/N>3, would be obtained by comparing current images to a set of reference images. Early detection is required to measure the risetime in a model independent fashion within a few days of explosion and to allow identification well before peak brightness, approximately 3.8 magnitudes below peak. Note that the early discovery mitigates fast spacecraft scheduling. Twenty-two fields totaling 7.5° square degrees would be repeatedly studied with a repetition rate of every four days in the north field (and later repeated in the south field).

Photometry. Photometric study of the supernova lightcurve by obtaining at least ten data points along the development of the lightcurve at fairly uniform intervals. Photometry for the supernova is obtained primarily in the rest-frame B-band of the supernova using a filter set that approximates redshifted B-band filters. An overall fit to the lightcurve in both time and color space (using U, V, R, & I rest-frame filters) will be required to obtain the lightcurve parameters and to correct the data for dust extinction. To achieve this requirement, rest-frame B-band data points would be taken at peak brightness (S/N>30), at 0.5 magnitude below peak (S/N>30) (two measurements at rise and fall of lightcurve), at 1.0 magnitude below peak (S/N>20), at 1.5 and 2.0 magnitude below peak (S/N>15), and at 2.5 magnitude below peak on trailing edge of lightcurve (S/N>10) except in the IR channel where this last requirement does not apply. U,V,R&I-band color photometry is obtained simultaneously. Restframe photometry in B-band is redshifted into the observer frame by $(1+z)$. An optimal redshifted B-band filter set would eliminate a principal source of systematic error from the k-corrections. The photometry will require both optical and NIR coverage.

Spectra: In order to classify the supernova as Type Ia a spectrum is obtained at peak magnitude. The defining signature of a Type Ia supernova is the SiII feature at 6250A. Spectral luminosity indicators include the SiII features and the CaII features near 3950A, the observing time requirements are based on the CaII features for simplicity. Beyond a certain minimum resolution, there is a range of resolution and signal-to-noises that will satisfy this observing requirement: ($\lambda/\delta\lambda$>60, S/N>20), ($\lambda/\delta\lambda$>70, S/N > 14), or ($\lambda/\delta\lambda$ > 100, S/N >10) in the supernova-frame 3500-4200A. This leaves some flexibility in the design of the different arms of the spectrograph. In the optical regime, a single medium resolution spectrograph extending from 3500A to

10000A would satisfy SiII line measurement to z< 0.6, and the CaII feature requirement to z<1.5. A medium resolution NIR arm would satisfy the supernovae with redshift silicon-feature requirement beyond z>0.6, and the CaII feature in the range 1.5<z<1.7.

Redshift. Obtain pre-explosion host galaxy redshift estimate based on photometric redshifts (only once per field) based on images in multiple filters to S/N>30. Obtain accurate host galaxy red-shift from at-peak supernova spectrum or final reference spectrum; this requires access to redshifted H-alpha or 4000A break. These features are close to the key supernova features (CaII, SiII), so the requirements for the spectroscopy are sufficient.

Off-peak spectra (evolution). On a small (eg. 10%) subset of the data obtain a spectrum at off-peak brightness along lightcurve for z<0.7 to check for evolution of spectral features. Wavelength range is from 3000A to 6500A in the restframe of the supernova.

Host galaxy spectroscopy: Obtain host-galaxy final reference spectrum, and measure redshift from at-peak supernova spectrum and/or final reference spectrum. The spectrograph will sample host-galaxy light underneath and around the SN spectrum obtained at peak. This light must be subtracted, and in some cases this will require a final reference spectrum of the host-galaxy after the SN has faded. Individually or in combination these spectroscopic observations will be used to measure the host galaxy redshift when possible. Strong galaxy spectral features are H-alpha (6567A) and NII (6587A) for star-forming galaxies, and the spectral break at 4000A for quiescent galaxies. These spectral features are near in wavelength to key Type Ia supernova spectral features (SiII and CaII, respectively), and therefore do not impose additional requirements on the spectral coverage. Host galaxy spectroscopy benefits from the ability of the IFU to collect light over all or most of the face of the (resolved) galaxy. Host galaxy spectroscopy will benefit from the lowest possible readnoise and dark current from the spectrograph detectors. Ground-based spectroscopic observations will help support this requirement.

3.3 Optical Photometry

The requirement for supernova detection and photometry in the visible light domain is fulfilled by a large field imager based on CCD technology. The pixel size is chosen to be as low as attainable in science grade imagers to minimize the overall size of the focal plane while providing adequate sampling of the point-spread function. Since the CCD’s occupy the same focal plane as the IR detectors the optimal pixel size is jointly constrained. The IR detectors under consideration are currently restricted to 18 μm pixel size so that the optimal sampling in the CCD’s is given by the ratio of the longest wavelengths each sees. For the CCD’s this dictates a 10.5 μm pixel size. The optical system is constructed from 36 3.5k x 3.5k devices with a 1.0 μm wavelength cut-off. With this pixel count and size the CCD’s are the same size as the IR devices. Each CCD has a 2x2 array of filters imprinted or mounted closely on the surface.

The high-resistivity p-channel CCD technology provides high quantum efficiency at 1000 nm since the fully-depleted devices are 200 μm thick and back-illuminated. The typical exposure time is 300 sec while the longest single exposure is set during spectroscopy, at 1000 sec. Multiple frames would be stacked and cleaned of cosmic rays during ground processing. The longest aggregated image representing one lightcurve point (summed from many exposures) in the imager is 0.9 hours. For the parameters given in Table 5, which assumes a 2-meter primary mirror and an overall system detection efficiency of 60%, the imager sensitivity is limited only by zodiacal light background.

Table 5. Optical Photometry Reference Model Specification

Field-of-view	Approximately 0.34 square degrees
Plate Scale	0.10 arcsec/pixel
Wavelength coverage	350nm - 1000nm
Detector Type	High-Resistivity P-channel CCD's
Detector Architecture	36 3.5k x 3.5k CCD's with 10.5 micron pixels
Detector Array Temperature	140 K
Detector Quantum Efficiency:	>80% @ 400-800nm
Read Noise	4 e- @100kHz
Exposure Time	300 sec (typical single exposures)
Dark Current	0.002 e-/s/pixel
Readout Time	20 sec
Exposure control	Mechanical shutter
Filters	6 bands

The optical devices will be fabricated by LBNL using a new state-of-the-art CCD based on ultra-high purity high-resistivity n-type silicon. These CCD's are fully-depleted and back-illuminated with superior response. The largest devices currently in operation at Lick Observatory are 2k x 2k with 15 μm^2 pixels. Currently, larger 2k x 4k devices are being packaged and devices with smaller 12.0, 10.5, and 9 μm^2 pixels have been tested. The technology has also been moved to a commercial foundry. Since the devices do not require thinning to obtain high sensitivity with back-illumination the devices are extremely robust and easier to fabricate in volume. Measurements at the LBNL 88" cyclotron also indicate significant enhanced radiation tolerance. Further information about this technology can be found at URL, http://www-ccd.lbl.gov. LBNL has a long history in the fabrication of very large silicon array detectors, the largest contains one-square meter of silicon detectors. A larger instrument, of forty square meters of silicon detector is currently in fabrication.

Given the very large number of CCD's, LBNL and IN2P3/France have also begun development of radiation hard multi-channel preamplifier/correlated double samplers developed on an integrated circuit. Appropriate radiation hard 16-bit analog-to-digital converters are currently under investigation. These IC's would be fabricated in a radiation tolerant process.

Detection of supernovae is accomplished by a repeated comparison of fixed fields to reference images. The imager would obtain twenty-two discovery fields from dark regions around the north and south ecliptic poles. These discovery fields would be recorded at four day intervals. The optical photometer obtains frames in each of the six redshifted B-band filters with exposures of sufficient duration to obtain all the data points required to reconstruct the lightcurve. Each of the ten datapoints correspond to up to approximately 0.7 hours. The optical photometry is obtained at regular intervals in order to obtain data points that reasonably approximate the required ten photometric points along the lightcurve.

3.4 IR Photometry

The requirement for supernova detection and photometry in the NIR light domain is fulfilled by a large field imager based on HgCdTe technology. Since the HgCdTe detectors occupy the same focal plane as the CCD detectors the optimal pixel size is jointly constrained. The IR detectors under consideration are currently restricted to 18 μm pixels. The IR system is constructed from 36 2kx2k HgCdTe devices with a 1.7 μm wavelength cut-off (or longer). This cut-off is a good match to the cut-off the thermal emissions from the approximately room temperature operating point of the optical surfaces of the telescope and provides adequate dark current at the 140K operating temperature of the focal plane. The requirements for the IR photometer are shown in Table 6. The devices have a single fixed filter on each device.

Following the supernova lightcurve in the infrared will require the highest possible throughput and quantum efficiency. The parameters given in Table 5 assume a 2 meter primary mirror and an overall IR system detection efficiency of 40% including telescope obscuration, reflectance, optical transport, and detector quantum efficiency. With these parameters the IR photometer is only limited by zodiacal light background. HgCdTe arrays are known to have strong intrapixel sensitivity variations. Therefore, a careful study of the dithering pattern will be undertaken to ensure that the IR photometer will produce accurate, unbiased photometry. Each of the ten datapoints correspond to up to approximately 1.8 hours. The NIR photometry is obtained at regular intervals in order to obtain data points that reasonably approximate the required ten photometric points along the lightcurve.

Table 6. NIR Photometry Reference Model Specification

Field-of-view	Approximately 0.34 square degrees
Plate Scale	0.17 arcsec/pixel
Wavelength coverage	900nm - 1700nm
Detector Type	HgCdTe Hawaii-2RG (1.7 μm cut-off)
Detector Architecture	36 HgCdTe 2kx2k Array's with 18 micron pixels
Detector Array Temperature	140 K
Detector Quantum Efficiency:	>60% average
Read Noise	5 e- (multiple samples)
Exposure Time	300 sec (typical single exposures)
Dark Current	0.02 e/s/pix
Readout Time	20 sec
Exposure control	Mechanical shutter
Filters	3 bands

3.5 Spectroscopy

The architecture of both the spectrograph is based on an integral field spectrograph with an image slicer. The image slicer eliminates the need for a slit and greatly reduces the pointing accuracy required to place the supernova within the field of view of the spectrograph while preserving photometric accuracy because of the 100% filling factor. The optical spectrograph may require selectable resolution (or binning) in order to achieve an optimum of performance and exposure times. Furthermore, the spectral features of the high redshift supernovae are dilated by $1+z$, so that reduced resolution is a good match to standardizing the performance over all supernovae followed. The performance features of the spectrograph are shown in Table 7. The spectrograph is assumed to have a visible and NIR arm within a single instrument. The cross-over wavelength between the arms at 1 μm is obtained with a high throughput dichroic splitter.

The spectrographic images are obtained by pointing the satellite at each individual supernova one at a time during its peak brightness. The parameters given in Table 6 assumes a 2 meter primary mirror and an overall visible light system efficiency of 40% and an IR system efficiency of 30% including telescope obscuration, reflectance, optical transport, and detector quantum efficiency.

Table 7. Spectrograph Reference Model Specification

Spectrograph architecture	Integral field spectrograph, two arms
Wavelength coverage	350-980 nm, 980-1700nm
Plate scale	0.15 arcsec/pixel
Spatial resolution of image slicer	0.15 arcsec/slice
Pixel size	HgCdTe: 18 μm, CCD: 15-20 μm
Field-of-View	3 x 3 arcsec
Location	Mounted on focal plane
Resolution	$\lambda/\delta\lambda = 100$
Detector Type	CCD’s (visible arm), HgCdTe (NIR arm)
Detector Architecture	1k x 1k each CCD, HgCdTe; fully-redundant
Detector Array Temperature	140 K
Detector Quantum Efficiency:	80% <QE> (visible), 60% <QE> HgCdTe
Read Noise	2 e- (visible), 5 e- (NIR) multiple reads
Dark Current	0.001 e-/s (visible), 0.02 e-/s (NIR)
Exposure Time	1000 sec

3.6 Summary Rates

In sixteen months of study, as shown in Table 8, the satellite can discover, follow the lightcurve, and obtain spectra at peak brightness for 2000 Type Ia supernovae [not accounting for analysis or other on the ground induced efficiencies].

Table 8. Summary of North (or South) Field Survey

Redshift	*Peak SNe flux [e/s]*	*Zodiacal [e/s]*	*SNe Rate/deg/yr*	*#SNe followed/year*	*#SNe/survey*	*Spectroscopy [hrs/yr]*
0.1	842.7	0.11	1.1	8	11	0
0.2	202.2	0.13	3.5	26	35	2
0.3	87.0	0.15	6.5	48	64	5
0.4	47.8	0.17	9.6	71	95	11
0.5	30.0	0.19	12.5	93	124	22
0.6	20.6	0.2	15.0	112	150	39
0.7	15.0	0.21	17.2	128	171	64
0.8	11.4	0.22	18.9	137	183	96
0.9	9.0	0.23	20.3	134	179	130
1	7.3	0.23	21.3	127	170	168
1.1	6.0	0.24	22.0	116	155	205
1.2	5.1	0.24	22.4	106	142	248
1.3	2.9	0.49	22.6	97	130	297
1.4	2.5	0.50	22.6	89	119	351
1.5	2.2	0.50	22.5	80	107	403
1.6	2.0	0.50	22.3	70	94	447
1.7	1.8	0.51	22.0	60	80	480
total				**1502**	**2009**	**2968**

4. Mission Requirements

The purpose of this section is to define the mission requirements placed upon SNAP organizations.

Launch.

The SNAP Observatory shall be launched into a final orbit having a 3 day synchronous orbit with an apogee of 25 R_e and a 26º inclination using a Delta IV or equivalent vehicle.

Orbital Adjustment.

The SNAP Observatory shall have on-board propulsion capable of: (i) offsetting initial injection errors, (ii) set and maintain the orbit period to a multiple of earth rotations; (iii) set and maintain the phase of the orbit with the SNAP Ground Station, and (iv) unload angular momentum from the reaction wheels.

Lifetime.

The SNAP Observatory shall be designed for a four-year lifetime.

Pointing.

The SNAP Observatory shall be stable to better than ±0.03 arcsec (1 sigma) [requirement], ±0.01 arcsec (1 sigma) [specification].

Engineering.

The SNAP Observatory shall be designed with S-band communications for commanding and engineering data downlink on a daily basis.

Science Telemetry

The SNAP Observatory shall be capable of storing at least 350 Gbytes of Instrument Data for one orbit and replaying that data at high rate to the SNAP Ground Station in a single perigee pass. In addition, the satellite must maintain a capability to transmit occasional instrument data to establish and maintain optical focus, and provide for check-out.

DeOrbit.

The SNAP Observatory shall maintain on-board capability to de-orbit at end of its useful life as required by NSS 1740.

5. Ground Systems Requirements

5.1 Mission Operations

Mission Operations Center

The SNAP Observatory shall be controlled from a Mission Operations Center (MOC) capable of monitoring both spacecraft and instrument health and safety, while validating and uplinking SNAP observing schedules generated by the Science Operations Center (SOC).

The MOC shall be capable of receiving SNAP science and engineering telemetry at the full downlink rate of 300 Mbps, and temporarily storing at least one orbit's worth of data.

The MOC shall transfer science and selected engineering data to the Science Operations Center (SOC) concurrent with spacecraft contacts, and shall be capable of retransmitting science data to the SOC from its temporary storage in the event data data corrupted in transit to the SOC.

The MOC shall deliver to the SOC at least 98% of all SNAP available science data.

Ground Station.

The SNAP Ground Station shall be capable of S-Band communications with the SNAP Observatory at engineering rates to its apogee.

The Ground Station shall be capable of receiving Ka-Band science telemetry at 300 Mbps or greater.

5.2 Science Operations

Science Data Storage and Archiving

The Science Operations Center shall receive and store all SNAP Observatory Science Data and all necessary ancillary engineering data from the Mission Operations Center, and provide copies as required by the Data Management Plan to other facilities.

SuperNova Detection and Selection.

The Science Operations Center shall detect Supernovae in the images and select Supernovae for follow up measurements.

Guest Observations

The Science Operations Center shall provide access to available imaging time on the SNAP Observatory through an organized science program run by the PI institution.

Observation Schedule Management
The Science Operations Center shall optimize the SNAP Observing schedule in order to (i) achieve a relatively uniform distribution of Supernovae redshifts; (ii) meet the science requirements in minimum time; and (iii) provide access by the guest observer program.

5.3 Mission Data Requirements

Science Data Management
The SNAP Principal Investigator team shall be responsible for initial analysis of the data, its subsequent delivery to an appropriate data repository, the publication of scientific findings, and communication of results to the public. Additionally, the SNAP PI team shall be responsible for collecting engineering, and ancillary information necessary to validate and calibrate the scientific data prior to depositing it into an approved data repository. The dataset would likely be split into: 1) a co-added deep static dataset, and 2) a transient dataset. Data release will include making data available on-line at the DOE National Energy Research Scientific Computing Center located at LBNL and/or through other centers. The SNAP archival data will be made available to the public and the science community. Additionally, we expect to be able to provide a significant and ever increasing fraction of the SNAP observing time in a restricted mode to meritorious survey programs.

Data Management Plan
SNAP Management shall develop a data management plan to address the total activity associated with the flow of science data, from acquisition, through processing, data product generation and validation, to archiving and preservation.

6. Education and Public Outreach

The SNAP project shall develop and execute an Education and Public Outreach Plan. The program will make use of the intense public interest in the accelerating universe as a unique opportunity to engage students, educators, and the general public in an enhanced understanding of our physical world. The program shall address grades K-14 students and teachers, the general public, as well as upper-level undergraduates and graduate students pursuing advanced degrees in the sciences and engineering disciplines.

7. Spacecraft

In Table 9, the critical specifications for the SNAP spacecraft are given. Many of these specifications are still under development to allow design trade-off flexibility.

Table 9. Spacecraft Specifications

Launch Vehicle	Delta 4240 or equivalent, maximum lift to orbit 2040 kg
Mission Lifetime	4 years
Orbit	HEO (2.56 Re x 24.94 Re), 3-day synchronous
Telemetry	300 Mbit/s Ka-band, ~5 hr. pass @ perigee
Spacecraft attitude control	3-axis stabilized, low jitter
Pointing jitter z axis (rotation)	< 50 microradians/exposure (3 sigma) (1 μrad = 0.2 arcsec)
Pointing jitter x-y axis	Focal plane stabilized by ACS using focal plane feedback to 0.01 arcsec/exposure (1 sigma, 1-D).
Exposure time	Maximum single exposure 3000 sec, 300 sec typical.
Bore of Spectrograph	3 arcsec x 3 arcsec (FOV)
Pointing accuracy (instrument)	Place supernova within bore of spectrograph
Pointing knowledge (instrument)	Place supernova within bore of spectrograph
Slew Rate to new field	>3 degrees/minute
Acquisition time new field	< 20 seconds for field within 3 arcminutes
Observing Duty-Factor	>80%
Total Mass (Spacecraft & Payload)	1650 kg (wet)
Total Power (Spacecraft & Payload)	460W (average)
Solid State Recorder Capacity	350 Gbytes
Propulsion system	for attitude control and orbit disposal
Thermal control	telescope < 290K, focal plane array ≤140K
Solar Avoidance	70 degrees
Field of View	nominally centered near north and south ecliptic poles
Thermal management	passive coatings, thermal insulation, heaters, radiators
Redundant architecture	Failure mitigation & identification of critical components